Time Domain Laboratory

1.- Introduction

We will learn the basics of Time Domain Spectroscopy in this laboratory. You will have to align the THz beam path and characterize different materials.

Basics of Time Domain Spectroscopy

The basic setup of a Terahertz Time Domain Spectrometer is shown in Fig. 1. To understand the basic principle, we start with the emitter antenna that is biased and switched by an ultrafast laser pulse. The antenna is based on a biased semiconductor structure with a low carrier lifetime, such as LT-GaAs, for 800 nm excitation. While the semiconductor is not conductive unless excited, a short laser pulse generates carriers that are accelerated by the applied bias. Due to the short carrier lifetime in the material, the photocurrent drops rapidly in the time scale of the semiconductors decay rate. A closer analysis of this process shows that the radiation emitted during this process is proportional to the derivative of the photocurrent. The optical pulse in the range of some ten femtoseconds generates a terahertz pulse with a pulse width in the picosecond range.

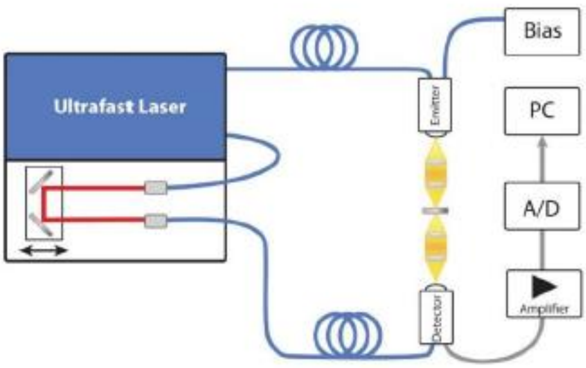


Fig. 1: Schematic of a Terahertz Time domain Spectrometer

The detection scheme is based on a similar principle. The detector antenna has a dipole shape with a small gap in the range of some micrometers. When excited with a femtosecond pulse, the antenna works as a dipole and the incoming terahertz pulse induces a small current.

The gap enables a stroboscopic sampling scheme. Since the antenna is blind unless illuminated by the pulsed laser source, the beam path difference between the terahertz path and the detector laser path can be used to sample the terahertz path in the time domain. Hence, the delay line can sample the picosecond pulse with a temporal resolution. Refer to Fig. 1 for the setup. Consequently, the measured data gives the electrical field as a function of time ($E(t)$). A short carrier lifetime and short laser pulses are crucial for the detection, since both affect the temporal resolution of the stroboscopic measurement.

Transmission Spectroscopy

A recorded reference signal $E_{ref}(t)$ is shown in black in Fig. 2(a). When introducing a sample into the beam path, two things happen. The lower propagation velocity in the sample delays the pulse in time and reflection and absorption lead to a lower signal amplitude. A sample of α-lactose (thickness $d \approx 1$ mm) gives the red signal $E_{sam}(t)$ shown in Fig. 2(a). Using the Fourier transform (FFT: Fast Fourier

Transform) the corresponding spectral range of both signals ($E_{ref}(\nu)$ and $E_{sam}(\nu)$, see Fig. 2(b)) and the phase ($\phi_{ref}(\nu)$ and $\phi_{sam}(\nu)$) are obtained. These can be used to calculate optical properties, e.g. absorbance and refractive index.

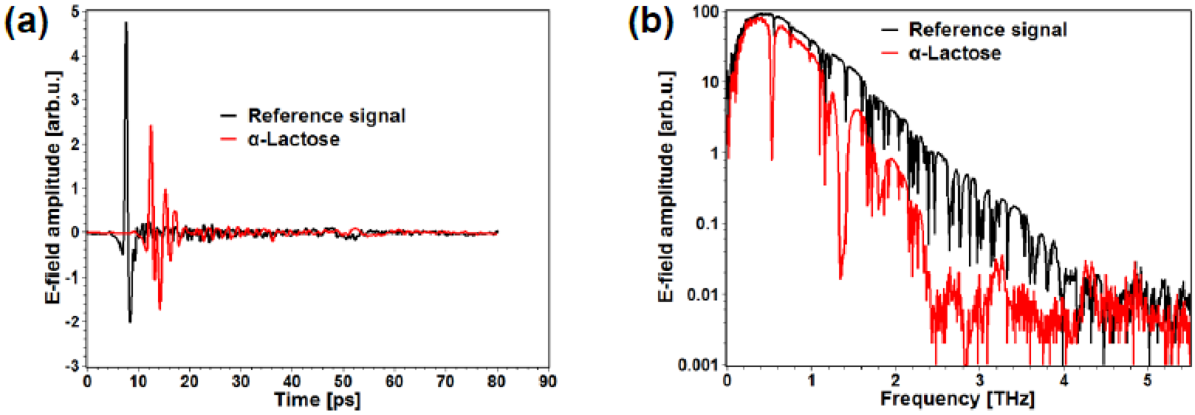
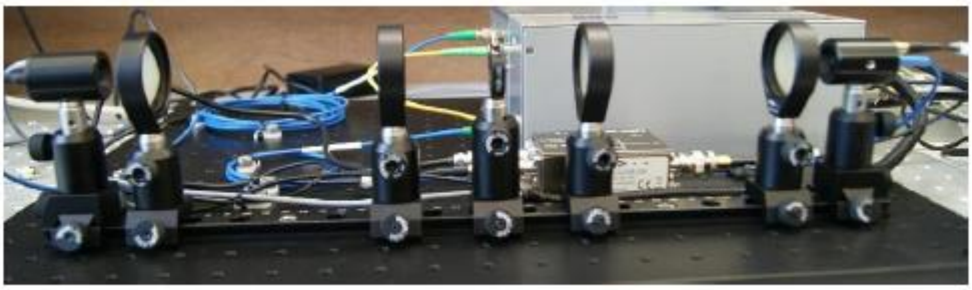


Fig. 2: Reference signal and α-Lactose signal as obtained from TDS. (a) E-field as a function of time. (b) E-field as a function of frequency

2.- Alignment of the Terahertz Beam Path

In the terahertz beam path (see Fig. 3), the terahertz radiation is guided from the emitter antenna to the detector antenna through four polymer lenses (lens 1 to lens 4). The lenses have an effective focal length of approximately 50 mm. The silicon lenses of the antenna pre-collimate the THz radiation. In between lens 2 and 3 (in the middle), an intermediate focal point is generated. The system can also be operated with a collimated THz-beam (without lens 2 and 3 inside the optical path). The THz radiation generated by the emitter antenna is linearly polarized, thus rotating one of the antennas will affect the performance of the spectrometer.



Emitter	TPX50	TPX50	Pinhole	TPX50	TPX50	Detector
35mm	70mm	190mm	245mm	305mm	400mm	435mm

Fig. 3: Alignment of the Terahertz path on 450mm rail. The values given are readings on the right hand side of the carriers for default setup. The values may vary by +/-5mm during alignment.

Assignment 1

Align all the lenses and maximize the pulse response

3.- Characterization of Different Dielectrics

After the THz beam path has been aligned and the pulse signal maximized, we can start characterizing different components.

Assignment 2

Place the three different dielectric slabs at the location where the pinhole is placed in the THz beam path and measure their pulse response. Transform the time signal into the frequency domain and extract the dielectric constant and the loss of the material. You will learn how to do this in the next lecture, and you will need to know the thickness of the sample you are trying to characterize.

Once you have the dielectric constant of the material, identify which dielectric it is using the table given in the Appendix A.

Appendix A: Table of Dielectrics

Material	Dielectric constant
Silicon	11.7
Silicon nitride	7.5
GaAs	12.4
HDPE	2.3
Teflon	2.1
Goretex	1.25
Polyamide	3.4